# Physique des saveurs

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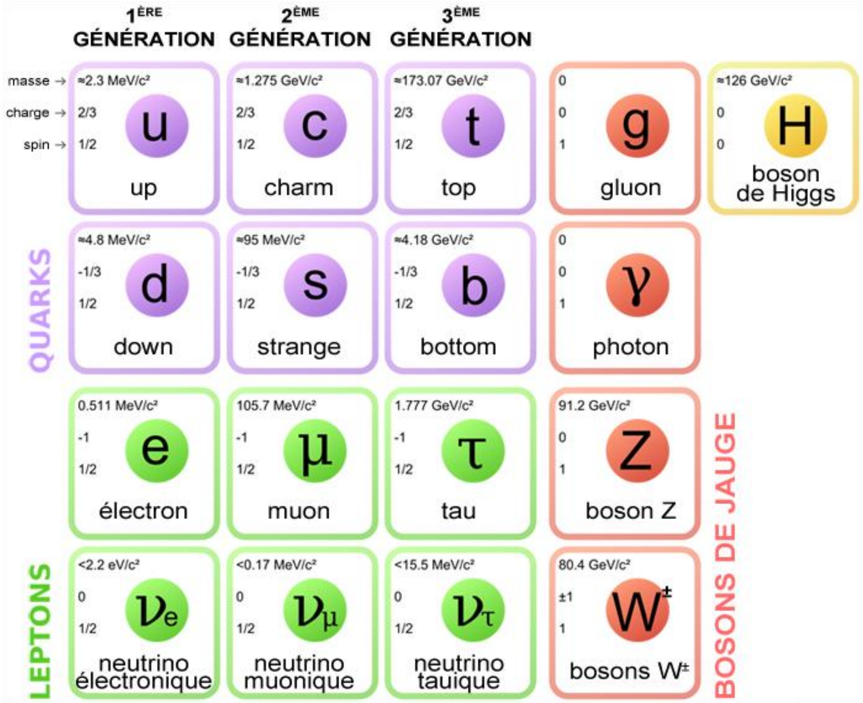
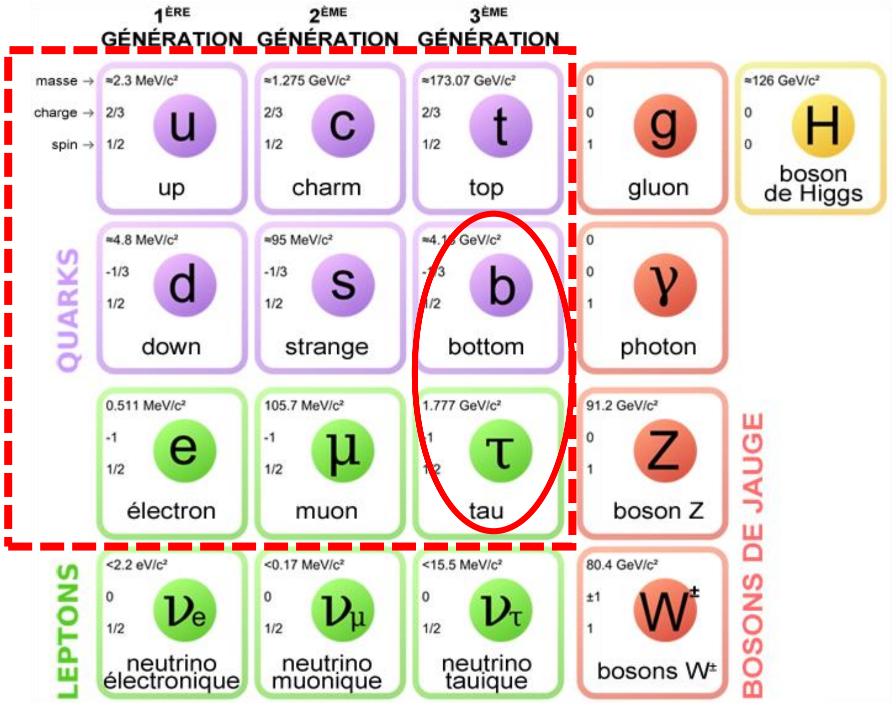
# The standard model of particle physics



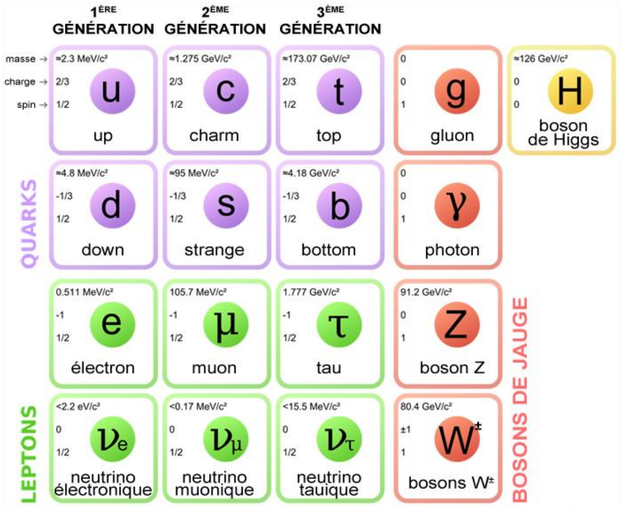
# The standard model of particle physics

Flavour physics



# What we do know

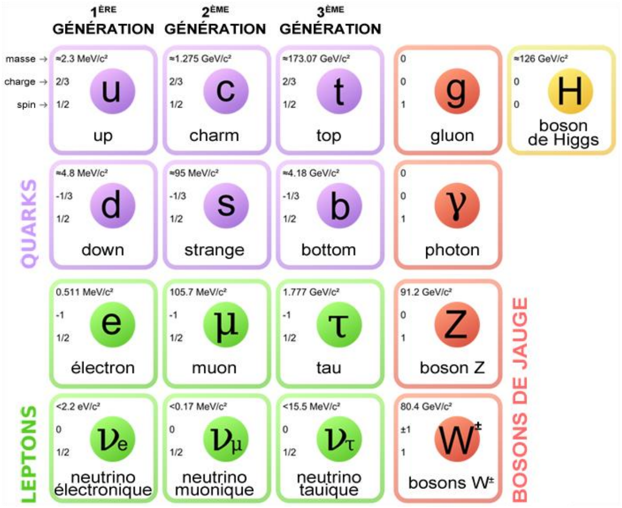
- 4% of the Universe content: matter, described by the Standard Model



# What we do know

# What we don’t know

- 4% of the Universe content: matter, described by the Standard Model



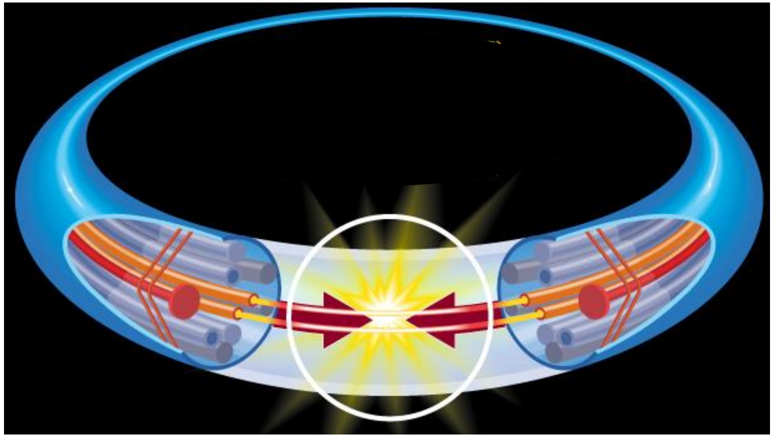

- 96% of the Universe content: dark matter and dark energy
- Why is Universe made of matter and not antimatter
- Why 3 families in the SM
- ….

→ New Physics

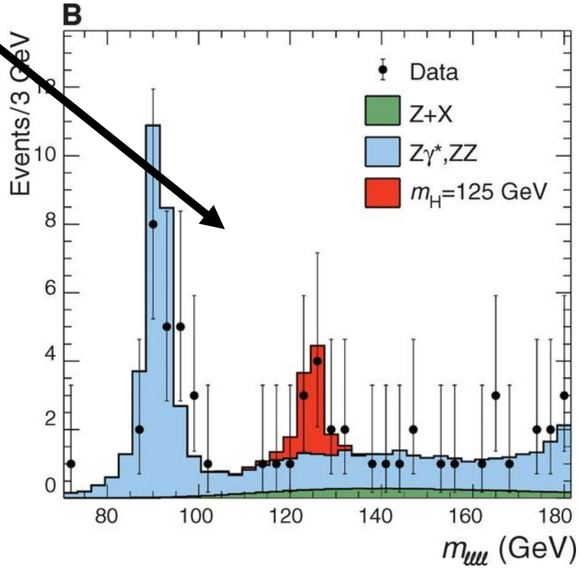
# Search for New Physics

**Direct** search for new particles (LHC experiments ATLAS and CMS)

$E=mc^2$



Particle accelerator




New particles

# Search for New Physics

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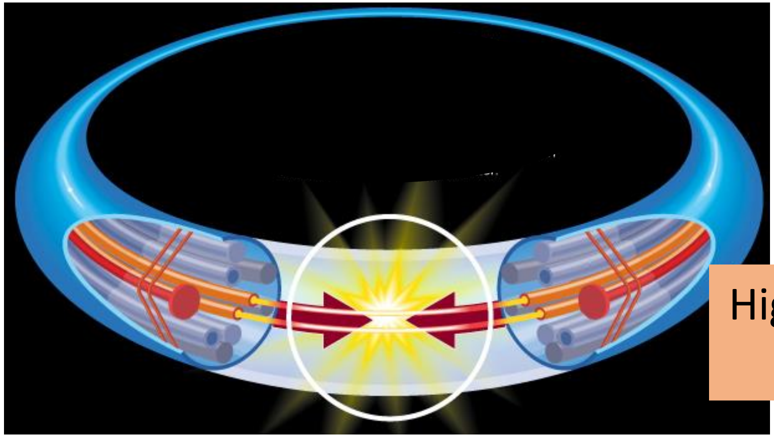
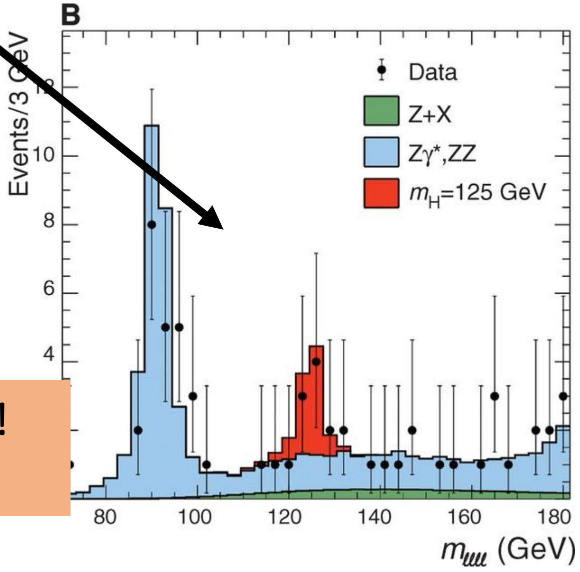


Particle accelerator

High energy needed!
→ LHC



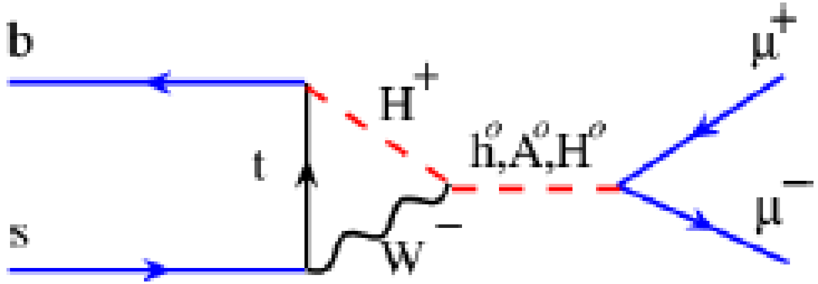

New particles

# Search for New Physics

**Indirect** effects through high precision tests of SM (LHCb, Belle II,…)

$$\Delta t \times \Delta E \approx h / 2\pi \longrightarrow$$

New particles can appear during a short time, modifying the property of a decay



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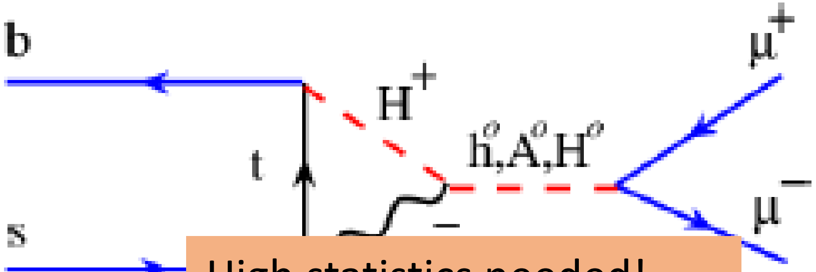



High statistics needed!
LHC, SuperKEKb

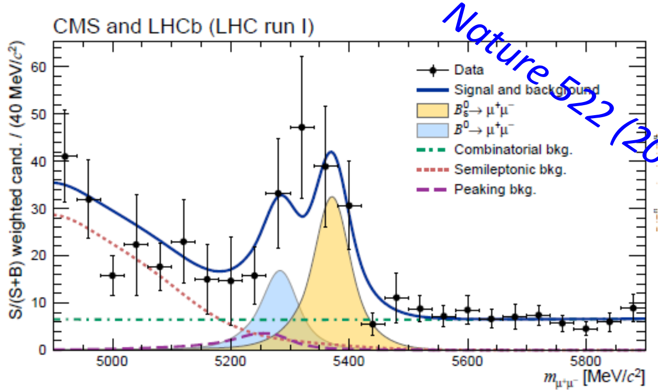
# In practice, we can

- Measure quantities precisely predicted by the SM, ex : $B_s \rightarrow \mu\mu$

SM = $(3.65\pm0.23)\mathrm{x}10^{-9}$

LHCb latest measurement:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.09\,^{+0.46}_{-0.43}\,^{+0.15}_{-0.11}) \times 10^{-9},$$

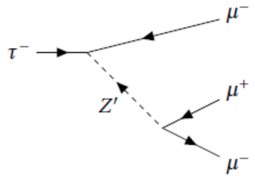



Nature 522 (2015) 68

- Look for forbidden decays

  Ex: lepton number violating, lepton flavor violating

$\tau \rightarrow \mu\mu\mu$

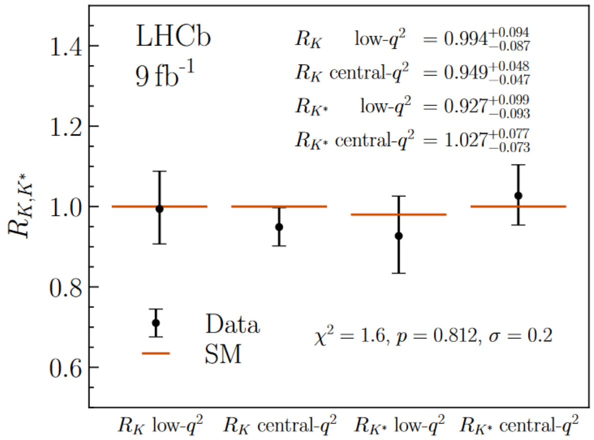


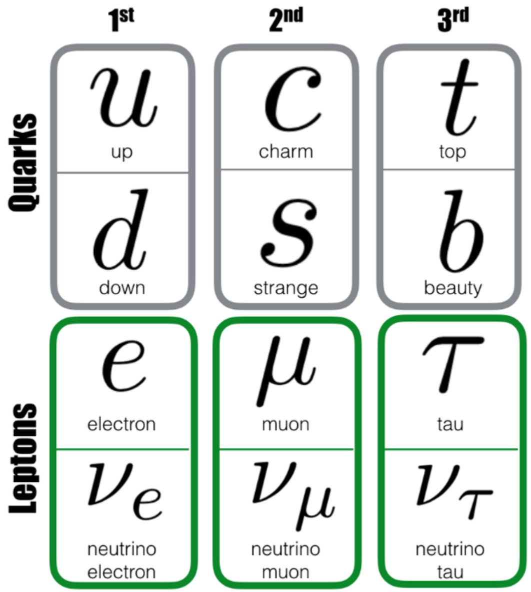

Observation would be a clear sign of NP!

# In practice, we can

- Test properties of SM
  Ex: lepton flavor universality

$$R_K = \frac{\Gamma(B^+ \to K^+ \mu^+ \mu^-)}{\Gamma(B^+ \to K^+ e^+ e^-)}$$



# The experiments

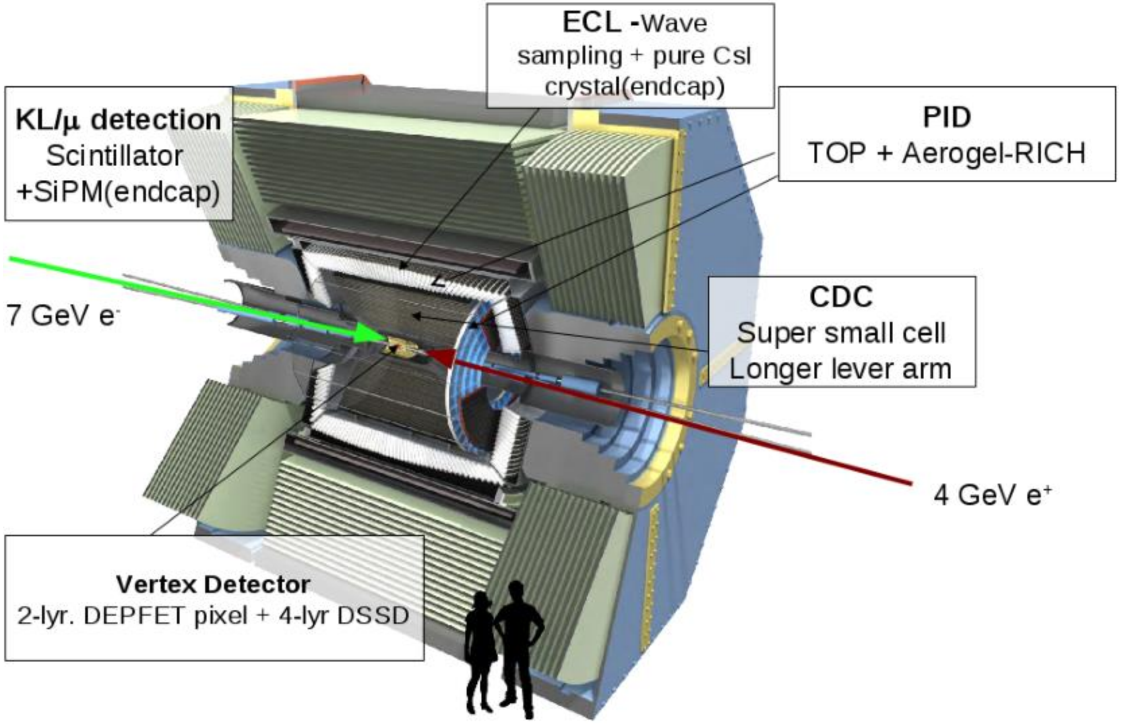
Belle II at SuperKEKB

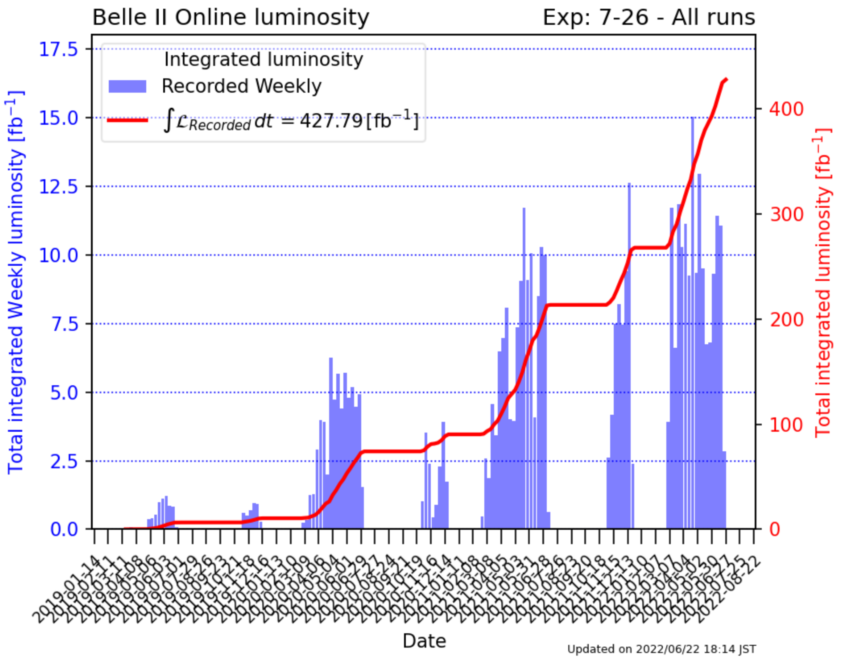
LHCb at the LHC

# SuperKeKb in Japan

- $e^+e^-$ collider, located at KEK, 60km from Tokyo
- Working at 10.58 GeV to produce b quark pairs
- Started in 2019
- Most intense accelerator!

# Belle II

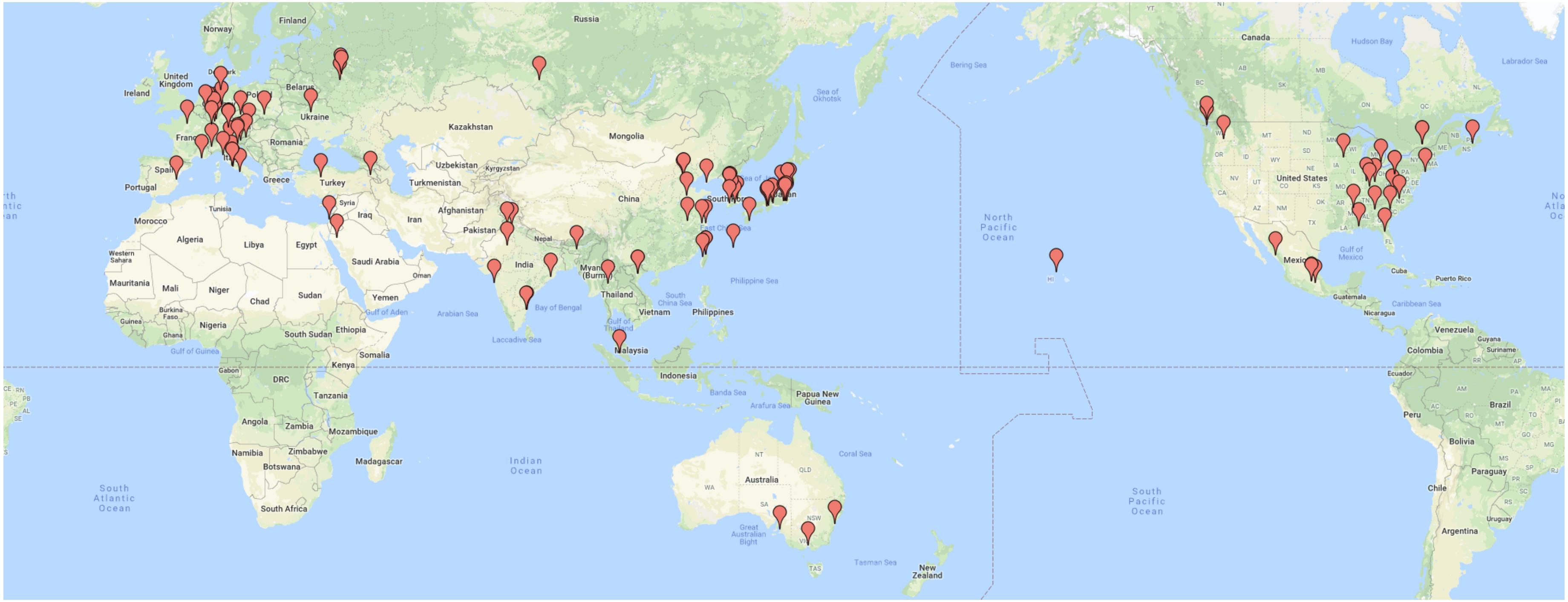



Experiment restarting after 1.5 year of shutdown

# Belle II collaboration

~1000 physicists
In France: Orsay, Strasbourg, Marseille



# Belle II collaboration

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In France: Orsay Strasbourg, Marseille

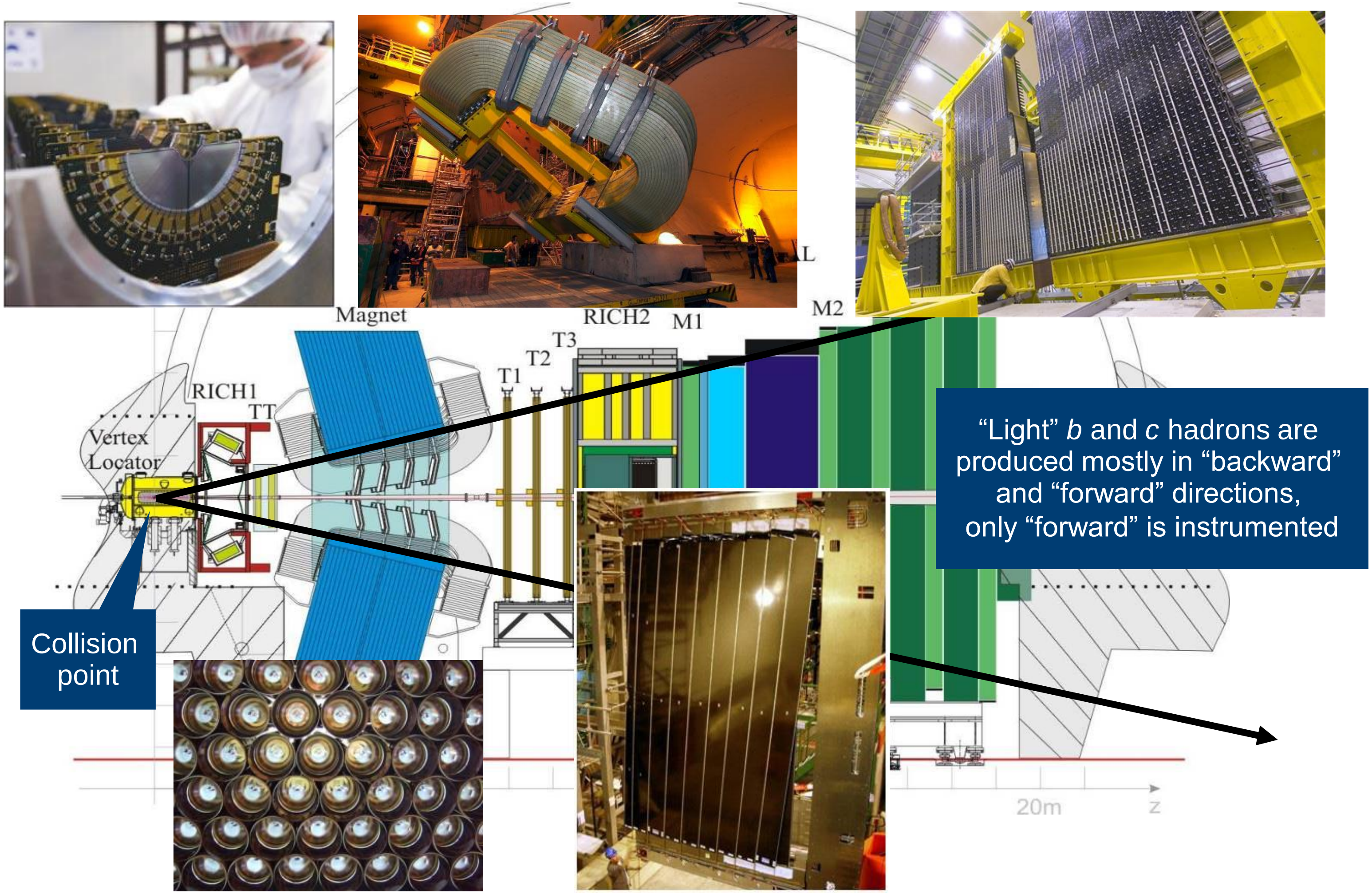
# Belle II @CPPM

- Group created in 2019
- 3 seniors / 2 postdocs / 3 PhD
- Activities:
  - Search for lepton flavor violating decays of $\tau$ lepton and B meson
  - Tracking performance studies, improvement of tracking algorithms
  - Operation of the silicon vertex detector
  - Development of new vertex detector
  - …

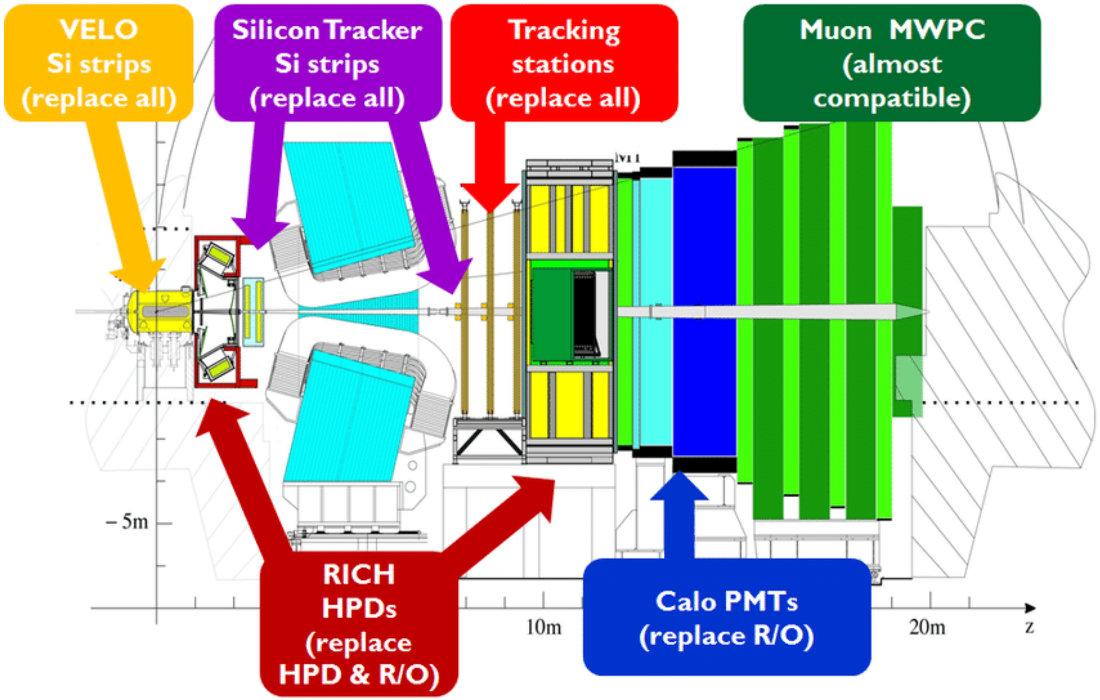
https://www.cppm.in2p3.fr/Belle2/en/

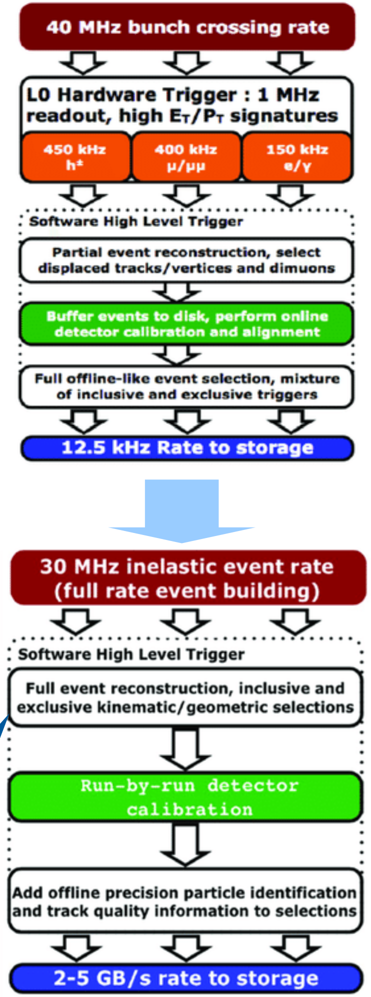
If interested, contact Justine Serrano (serrano@cppm.in2p3.fr)

# LHCb experiment (2011-2018)



# Upgraded LHCb (2022-)




Increase luminosity by ~x5

Major detector, data acquisition
and trigger upgrade
(including fully software trigger on GPU)

# LHCb group at CPPM

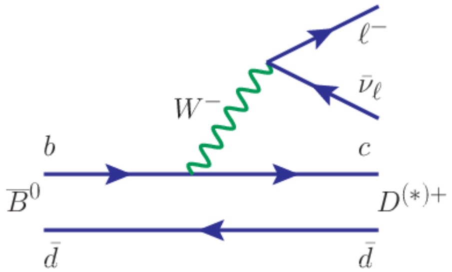

**Main activities of the group:**

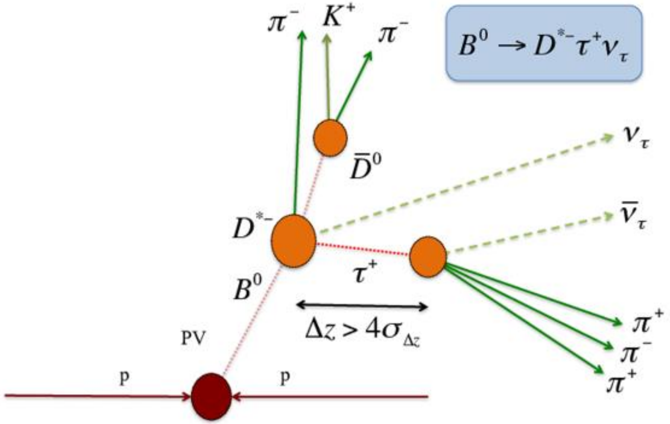
- Analyses: charged anomalies (semileptonic B decays)
- DAQ electronics (PCI readout boards)
- Trigger (HLT1 on GPU and HLT2 on CPU)
- Preparation for Upgrade II: vertex detector sensors

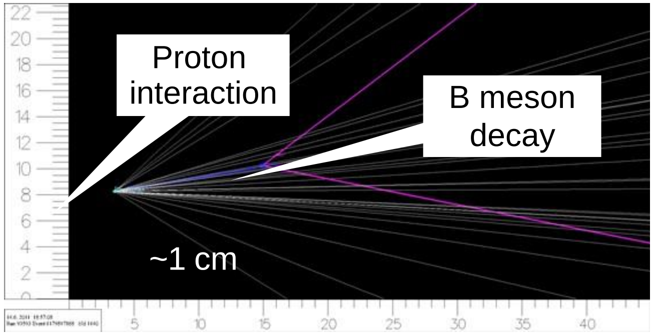
# Lepton flavour universality: b→clν

Study **charged weak current:** e.g. $R(D^*) = \dfrac{BR(B^0 \to D^{*-}\tau^+\nu_\tau)}{BR(B^0 \to D^{*-}\mu^+\nu_\mu)}$

- Tricky: neutrinos are **not** reconstructed
- Use event **topology** for kinematic constraints
- Use **machine learning** algorithms trained on simulated signal and backgrounds



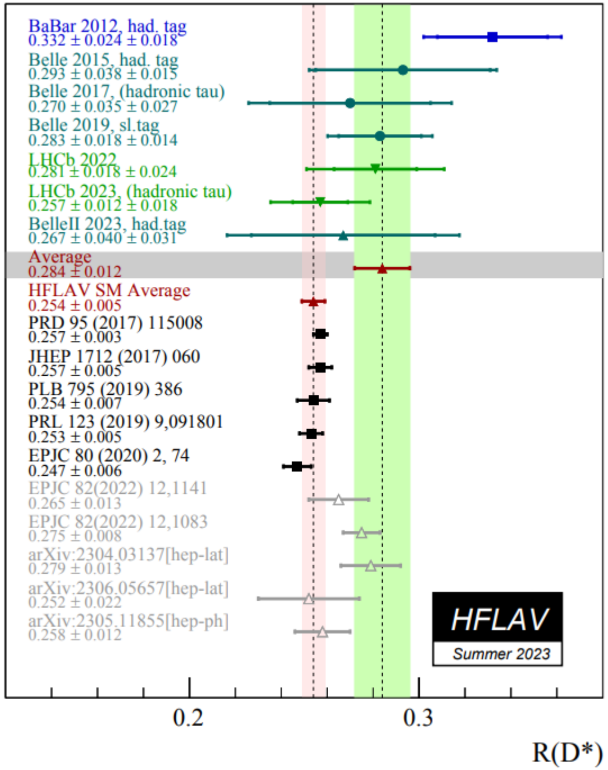



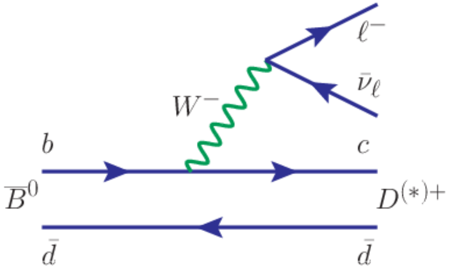
# Lepton flavour universality: b→clν

Study **charged weak current:**

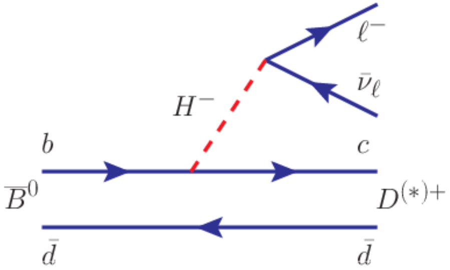
$$R(D^*) = \frac{BR(B^0 \to D^{*-}\tau^+\nu_\tau)}{BR(B^0 \to D^{*-}\mu^+\nu_\mu)}$$

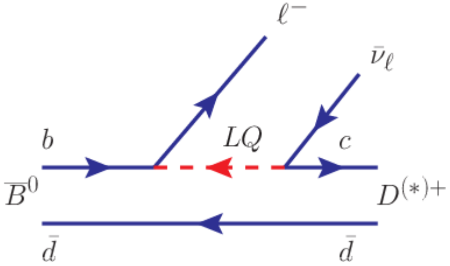
All measurements are systematically **above** SM!




Can be explained by "**New Physics**":



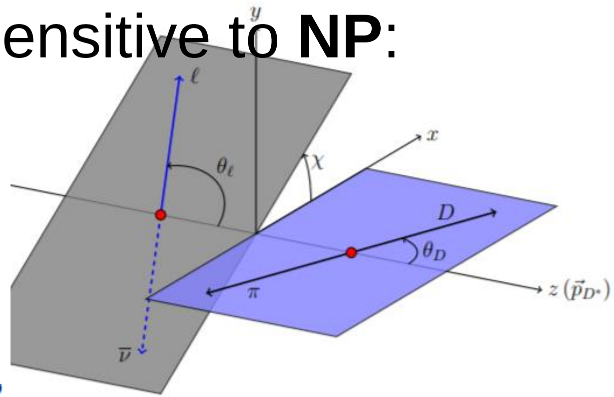



# Semileptonic B decays: other than *R(D*)*

Investigating other observables sensitive to **NP**:

- Angular distributions:

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_D d\cos\theta_\ell d\chi} = \frac{9}{32\pi}\Big\{ I_{1c}\cos^2\theta_D + I_{1s}\sin^2\theta_D$$
$$+ \left[I_{2c}\cos^2\theta_D + I_{2s}\sin^2\theta_D\right]\cos 2\theta_\ell$$
$$+ \left[I_{6c}\cos^2\theta_D + I_{6s}\sin^2\theta_D\right]\cos\theta_\ell$$
$$+ \left[I_3\cos 2\chi + \boxed{I_9\sin 2\chi}\right]\sin^2\theta_\ell\sin^2\theta_D$$
$$+ \left[I_4\cos\chi + \boxed{I_8\sin\chi}\right]\sin 2\theta_\ell\sin 2\theta_D$$
$$+ \left[I_5\cos\chi + \boxed{I_7\sin\chi}\right]\sin\theta_\ell\sin 2\theta_D\Big\},$$




Parity- and
CP-violating terms
≡ 0 in SM

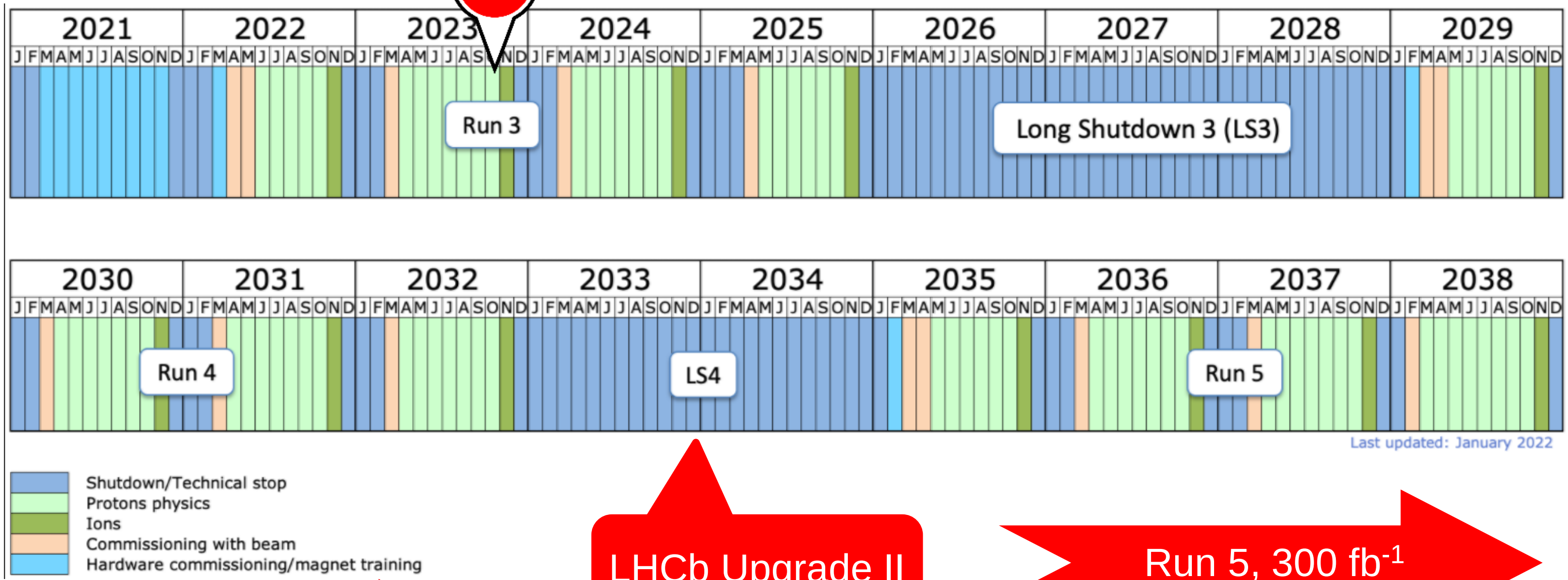
- LFU observables with electrons: $R_{e\tau}(D^*)$, $R_{e\mu}(D^*)$
- Decay with other *D* states: orbital *D* excitations
  - Master internship and PhD project in 2024
  - Contact Anton Poluektov ([Anton.Poluektov@cern.ch](mailto:Anton.Poluektov@cern.ch))

# LHC long-term schedule

LHCb Upgrade I

Run 3, 25 $fb^{-1}$

Run 4




LHCb Upgrade II

Run 4, 25 $fb^{-1}$

$L = 2x10^{33}$

Run 5, 300 $fb^{-1}$

$L = 2x10^{34}$, $\mu$=50

~400 Tb/sec at readout

Thanks!